# Embedding Learning Through Multilingual Concept Induction


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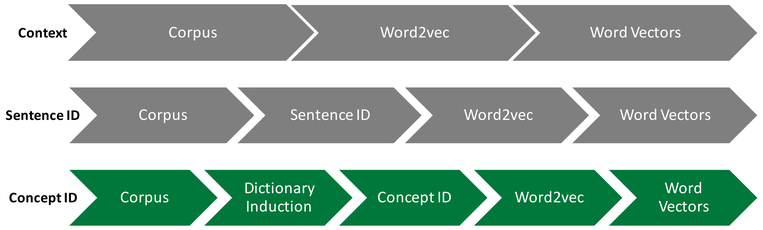
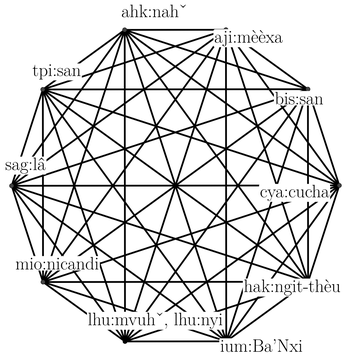
## Motivation




Objective: **Multilingual wordspace with 1000s (low-resource) languages.**

New feature: **concept-IDs**.

## The concept "sun"




```
[...]
ell4:ήλιου aby0:eweka aby0:ewekanu aby0:ewekaini wrs0:okombava
wrs0:okomba wrs0:okombam cbs0:badi bjr0:súani bjr0:Súani
bjr0:afu deu2:Sonne engb:the engb:sun fra2:soleil hwc1:sun
hwc1:da med0:ant nob3:solen nob3:Solen spa1:sol sua0:kolkha
sua0:a tir0:ጸሓይ slv0:sonce slv0:sonca slv0:Sonce snn2:xɨcaj
xav0:bâtâ arb1:شَمْس mcp0:jwɔ́wʉ́d mcp0:yásə́ mco0:xɨ́ɨ́ mcd0:fari
men0:foloi mdy0:ዓሊ mdy0:ዓሊ mcf0:ushê tir1:ጸሓይ tur4:güneş
tur4:güneşe tur4:Güneş zho3:太陽 zho6:日頭
[...]
```

| | roundtrip translation for "sun" | | | |
|---|---|---|---|---|
| | S1 ($\mu$) | R1 ($\mu$) | S4 ($\mu$) | S16 ($\mu$) |
| S-ID | 61 | 61 | 83 | 99 |
| CLIQUE | **85** | **85** | **98** | **100** |

| ISO-639-3 | Language | Family | Region (example) |
|---|---|---|---|
| lhu | Lahu | Sino-Tibetan | Thailand |
| ahk | Akha | Sino-Tibetan | China |
| hak | Hakka Chinese | Chinese | China |
| ium | Iu Mien | Hmong-Mien | Laos |
| tpi | Tok Pisin | Creole | Papua New Guinea |
| mio | Pinotepa Mixtec | Oto-Manguean | Oaxaca |
| cya | Highland Chatino | Oto-Manguean | Oaxaca |
| bis | Bislama | Creole | Vanuatu |
| aji | Ajië | Austronesian | New Caledonia |
| sag | Sango | Creole | Central Africa |

## Contributions

1. Novel embedding learning method: **concept-based embedding learning**.
2. New word-/character-level **dictionary and concept induction** methods.
3. Word translation and sentiment analysis **across 1259 languages**.

## Conclusions

1. **Concept-based methods outperform** previous approaches.
2. New roundtrip evaluation is an **excellent wordspace quality indicator**.
3. **Character-level is better than word-level** for sentiment classification.

## Data

- Parallel Bible Corpus [Mayer and Cysouw, 2014]: 7958 verses, 1259 languages, 1664 editions.

| English King James Version | German Elberfelder 1905 | Spanish Americas |
|---|---|---|
| And he said , Do it the second time . And they did it the second time . . . And he said , Do it the third time . . . third time . | Und er sprach : Füllet vier Eimer mit Wasser , und gießet es auf das Brandopfer und auf das Holz . Und er sprach : Tut es zum zweiten Male ! Und sie taten es zum zweiten Male . . . Und er sprach : Tut es zum dritten Male ! Und sie taten es zum dritten Male . | Y dijo : Llenad cuatro cántaros de agua y derramadla sobre el holocausto y sobre la leña . Después dijo : Hacedlo por segunda vez ; y lo hicieron por segunda vez . . . Y añadió : Hacedlo por tercera vez ; y lo hicieron por tercera vez . |

## Dictionary Induction

- Creating $\mathcal{O}(n^2)$ dictionaries for $n$ languages not scalable
  $\Rightarrow$ selection of $p = 10$ pivot languages
- Computing $p(p-1)/2 + pn$ dictionaries (intra-pivot and pivot-target) by aggregating fast-align alignments.

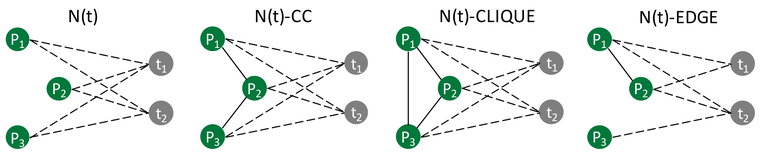
## Concept Induction

**1) CLIQUE Projection**

- In ideal world: concepts correspond to cliques in the multilingual dictionary graph.
- In real-world: identify quasi-cliques to accommodate noise.
- Identify concepts in pivot dictionary graph and project them onto target languages.

**2) Target Neighborhoods N(t)**

- Define target neighborhood for a word $t$ by $N(t) := \{w \in V_p \,|\, (w,t) \in E_D\}$.
- Two words $t_1$ and $t_2$ are in the same concept if $N(t_1) = N(t_2)$.




## Baselines

- Non-wordspace based: **RTSIMPLE**. Roundtrip translation directly on the dictionary graph.
- Context-based wordspaces: bag-of-words (**BOW**) [Vulić et al., 2015], sentence-ID (**S-ID**) [Levy et al., 2017].
- Alternative concept-identification method: **SAMPLE** [Lardilleux et al., 2009]. Sampling based approach for identifying concepts in a sentence-aligned corpus. Projection step same as for CLIQUE.

## S-ID vs. C-ID

```
``...and gather his wheat into the garner ; but he will burn up the chaff
with unquenchable fire .''
```

| | $q$ | $\Rightarrow$ | $I_e(q)$ | $\Rightarrow$ | $T_e(q)$ |
|---|---|---|---|---|---|
| S-ID | burn | $\Rightarrow$ | gogoro | $\Rightarrow$ | harvest labourers fowls wheat sow gather tares gnashing |
| | | $\Rightarrow$ | gbi | $\Rightarrow$ | fire burned brimstone hell burn burning smoke Sodom flame goats gnashing offerings vial devour wheat perdition |
| CLIQUE | burn | $\Rightarrow$ | agbi | $\Rightarrow$ | burn burned burning burning furnace fire flame warming unquenchable |
| | | $\Rightarrow$ | gbi | $\Rightarrow$ | burning burn fire furnace burned unquenchable flame warming smoke lampstands candle lamps extinguished lamp pool Hell |

| | roundtrip translation for "burn" | | | |
|---|---|---|---|---|
| | S1 ($\mu$) | R1 ($\mu$) | S4 ($\mu$) | S16 ($\mu$) |
| S-ID | 0.06 | 0.18 | 0.14 | 0.72 |
| CLIQUE | **0.72** | **0.92** | **0.95** | **1.00** |

- Roundtrip translation fails for query `burn` in language sag.
- Reason: `sag:gogoro` occurs only in the context of `burning`
- Nearest neighbours of `sag:gbi` within eng reflect the context of `burn` instead of semantically related words

## WORD vs. CHAR

```
[ksw] ဒီးတေၤ်ကမၣ်လၢအမာ်လၢမလီၢ်မၤကနၣ်သံၤ်,
      ၎်သုတ္ၢ်ပၢအဂ်အသးတၢၣ်ကၣ်ပီၤ်.
[cso] Hi³⁺sa³⁺jun³⁺lɨ̂³³⁺ma³⁺tson²⁻tsú²⁻
      lɨ̂³ua³⁺cáun²⁻tso³⁺ñí¹⁺hnâ³⁺ná²⁻.
[eng] Neither·can·they·prove·the·things·
      whereof·they·now·accuse·me··
```

Many hard-to-tokenize and morphologically rich languages
$\Rightarrow$ create 2 versions per edition: **WORD** and **CHAR**
**WORD** (whitespace tok.):
`[Neither, can, they, prove, the, things, ...`
**CHAR** (overlapping byte ngrams):
`[Neit, eith, ithe, ther, her@, er@c, r@ca, @can, ...`

**Adjustments:**

- $\chi^2$ **based dictionary:** iteratively select word pair with highest $\chi^2$. Then remove cooccurrence of this pair.
- **Query selection RTT:** find ngrams for each query word which correspond uniquely to this word.
- **Groundtruth in RTT:** select words based on degree of correspondance between ngram and query word.
- **Sentiment analysis:** consider only ngrams which have been aligned.

## Embedding Learning

- Word2vec skipgram model with mostly default hyperparameters.

**BOW**

- ...
- engw:. tpi:' mio:cuu mio:, engw:me engw:" mio:ri engw:. engw:You mio:chata mio:yuhu engw:years mio:Israel engw:They mio:ndo mio:yoo mio:sacahnu [...] tpi:animal engw:sky engw:and mio:vati
- sag:so ahk:, ahk:tsaw˜ sag:so ahk:law˜-eu¸ ahk:I˜sa_le_la˜ ahk:dah˜[...] ahk:yaw¸ sag:Nilaa ahk:ngeh¸ engw:. ahk:a¸ ahk:mi˜ ahk:je¸ ahk:gui˜ ahk:baw˜ ahk:du¸ engw:the ahk:m¸ engw:sky sag:ni engw:sun ahk:tse˜ ahk:ma sag:Nzapa ahk:ma¸ ahk:za¸
- ...

**S-ID**

- ...
- v4013 mio:Israel
- v4013 mio:ñivi
- v4013 mio:cati
- v4013 mio:tichi
- v4013 mio:nicandi
- v4014 mio:luhu
- v4014 mio:Cuhva
- ...

**Concept-Based**

- ...
- mdy0:ዓሊ guj0:સૂર્ય wca0:pili che0:Manx tgl3:ang C:30771:bis:san aeu0:nlma kor2:haywa xav0:bâdâ mmn0:na pol5:słońce
- ces1:Slunce blw0:init uig2:күн mio:nicandi mqb0:dav C:30771:bis:san engk:the eng7:the lug1:njuba qvn0:intis sld0:wpomi
- nma0:leimik amh2:ፀሐይ hmo0:dina ame0:atsne' zpm0:ngbidz C:52750:bis:san ium3:Mba'hnoi daa0:pat dop0:ilim xav0:Bâdâ hun5:nap
- ...

## Evaluation

**Roundtrip translation**

| $q$ | $\Rightarrow$ | $I_e(q)$ | $\Rightarrow$ | $T_e(q)$ | $S1$ | $R1$ | $S4$ | $S16$ |
|---|---|---|---|---|---|---|---|---|
| woman | $\Rightarrow$ | mujer | $\Rightarrow$ | wife woman women widows daughters daughter marry married | +0 | +0 | +1 | +1 |
| | $\Rightarrow$ | esposa | $\Rightarrow$ | marry wife woman married marriage virgin daughters bridegroom | | | | |

- 70 English queries taken from a list of universal words by Swadesh (1946).
- Strict and relaxed groundtruth: $G_s(q) = \{q\}$, $G_r(q)$ contains words with the same lemma as $q$.
- Accuracy computed by $1/|E| \sum_{e \in E} \min\{1, |T_e(q) \cap G_i(q)|\}$, aggregated over queries.
- $(i, |I_e(q)|, |T_e(q)|)$ is varied as follows: "S1"$(s,1,1)$, "S4" $(s,2,2)$, "S16" $(s,2,8)$, and "R1" $(r,1,1)$.

**Sentiment Analysis**

```
``Now is come salvation ... the power of his Christ:  for the accuser ...
cast down, which accused them before our God ...''
```

- Creation of English silver standard using the Vader-Classifier in combination with manual annotations
- Unclear sentiment: $\Rightarrow$ 2 tasks: "contains positive sentiment" and "contains negative sentiment"
- Assumption: each verse has unchanged sentiment across languages.
- Linear SVMs for classification and report of average $F_1$ scores (across languages)

## Results

| | | roundtrip translation | | | | | | | | | | | | | | | | sentiment analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | WORD | | | | | | | | CHAR | | | | | | | | WORD | | CHAR | |
| | | S1 | | R1 | | S4 | | S16 | | S1 | | R1 | | S4 | | S16 | | | | | |
| | | $\mu$ | Md | $\mu$ | Md | $\mu$ | Md | $\mu$ | Md | $\mu$ | Md | $\mu$ | Md | $\mu$ | Md | $\mu$ | Md | pos | neg | pos | neg |
| 1 | RTSIMPLE | 33 | 24 | 37 | 36 | | | | | 24 | 13 | 32 | 21 | | | | | | | | |
| 2 | BOW | 7 | 5 | 8 | 7 | 13 | 12 | 26 | 28 | 3 | 2 | 3 | 2 | 5 | 4 | 10 | 11 | 33 | 81 | 13 | 83 |
| 3 | S-ID | 46 | 46 | 52 | 55 | 63 | 76 | 79 | 91 | 65 | 9 | 5 | 9 | 5 | 14 | 9 | 25 | 22 | 70 | 79 | 88 |
| 4 | SAMPLE | 33 | 23 | 43 | 42 | 54 | 59 | 82 | 96 | 65 | 53 | **59** | 59 | **72** | 67 | 85 | 79 | 99 | 58 | 82 | 89 |
| 5 | CLIQUE | 43 | 36 | 59 | 63 | 67 | 77 | 93 | 99 | 69 | 42 | 46 | 48 | 55 | 60 | 76 | 73 | 98 | 53 | 84 | 89 |
| 6 | N(t) | **54** | **59** | **61** | 69 | **80** | **87** | **94** | **100** | 69 | 50 | 53 | 54 | 59 | 73 | 82 | 90 | 99 | 66 | 82 | 89 |
| 7 | N(t)-CC | 52 | 56 | 59 | 66 | 77 | 86 | 93 | 99 | 69 | 40 | 45 | 42 | 48 | 58 | 69 | 75 | 95 | 57 | 80 | 88 |
| 8 | N(t)-CLIQUE | 11 | 0 | 11 | 0 | 16 | 0 | 22 | 0 | 18 | 39 | 45 | 41 | 47 | 58 | 74 | 76 | 94 | 56 | 22 | 84 |
| 9 | N(t)-EDGE | 35 | 30 | 43 | 36 | 56 | 55 | 87 | 94 | 69 | 39 | 29 | 49 | 52 | 64 | 78 | 88 | **100** | 63 | 84 | **90** |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